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INTERNATIONAL PATENT APPLICATION PCT/EP03/00596
OUR REF : CR00548P C01/MAW
In response to the Examiner's Fax of 16th April 2004

Dear Sirs

With reference to the Examiner's Fax of 16th April 2004, the .Applicant wishes to amend further the claims of the application and herewith files new pages 3 to 5 and 17 to 22 to replace the corresponding pages 3 to 5 and 17 to 32 of the specification as filed, together with copies of the pages identifying the amendments made relative to the documents filed 12th March 2004. Support for the further amendments made can be found at pages 7, 8 and 11 of the specification as filed.

We believe that all the Examiner's objections have been met and allowance of the present application is respectfully requested. However, in the event that any other questions arise, the Examiner is invited to call the undersigned at +33 1 69 35 25 74.

Martin WHARMBY
Senior Patent Attorney
for the Applicant

for multiple antennas systems in the publication by G.J. Foschini and M.J. Gans, "On Limits of Wireless Communications in a fading Environment when Using Multiple Antennas", *Wireless Personnal Communications* 6:311-335, 1998. However, it has been demonstrated (in the publication by P. Loubaton, M. Debbah and M. de Courville, "Spread OFDM Performance with MMSE Equalization", in *International Conference on Acoustics, Speech, and Signal Processing*, Salt Lake City, USA, May 2001) that V-BLAST algorithms are not suited for conventional SOFDM systems due to the averaging of the SNRs (signal/noise ratios) at the receiver across the carriers during the despreading step. Moreover, such approaches lead to a tremendous decoding complexity due to the computation of several pseudo inverse matrices.

A need therefore exists for an OFDM communication system and decoding algorithm for use therein wherein the abovementioned disadvantage(s) may be alleviated.

Statement of Invention

The present invention provides a method of decoding a received spread OFDM wireless communication signal, and a receiver comprising decoding means for decoding a received signal by such a method, in a spread OFDM wireless communication receiver, as described in the accompanying claims.

In one embodiment of the present invention, the decoding algorithm comprises splitting a received block into two equal parts, one of the parts being decoded first and then subtracted from the received vector to suppress part of the interference and the other of the parts being decoded next. This iterative procedure can be further extended by successive block splitting and results in a multi-resolution decoding algorithm. An attractive property of this algorithm is that although it still relies on the computation of pseudo-inverses, the expressions of these pseudo-inverses are easy to derive and may consist simply in the product of a diagonal matrix by a Walsh Hadamard transform. Thus, using Walsh Hadamard spreading sequences, the inherent complexity penalty of a V-BLAST decoding schemes is simply removed. This allows a significant gain in performance (e.g., around 3-4dB compared to MMSE SOFDM) with only a modest increase in complexity, which motivates:

i) the use of such new modulation schemes in practice and

ii) their proposal as a solution for future wireless LAN standards.

The following technical merits of the multi-resolution decoding algorithm of this embodiment of the present invention can be highlighted:

- Low arithmetical complexity compared to existing SIC BLAST techniques with same or better performance.
- Flexibility and scalability of the method (it is possible to adjust the number of iterations to be

performed based on a performance/complexity tradeoff).

- Can be combined into all OFDM standards as a proprietary transmission mode (since it can be

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Claims

1. A method of decoding a received spread OFDM wireless communication signal comprising: performing an equalizing and decision function on the received spread OFDM signal (y), splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^i of portions ($\hat{s}_1$, $\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$), such that $\hat{s} = \begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \\ \vdots \end{bmatrix}$, where i is positive integer;

characterised by: for each of said portions ($\hat{s}_1$) of the equalized and decided signal block in turn subtracting values M ($M \begin{bmatrix} 0 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \\ \vdots \end{bmatrix}$) derived from the other portions ($\hat{s}_2$ to $\hat{s}_4$ ...) of the equalized and decided signal block from the received signal block (y) to produce a respective difference signal, where $M = H \cdot W$, H is an NxN diagonal matrix related to the complex frequency channel attenuations and W is an NxN unitary spreading matrix; and performing an equalising and decision function on the respective difference signal to produce a further processed equalized and decided portion ($\hat{\hat{s}}_1$) of the received signal in which interference due to the other

portions ($\hat{s}_2$ to $\hat{s}_4$) of the equalized and decided signal block is substantiallyreduced;
the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion being repeated for each of the other portions ($\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$) of the signal block.

2. A method as claimed in claim 1 wherein repeating subtracting the values derived from other portions of the equalized and decided signal block from the received signal to produce a respective further difference signal comprises subtracting values derived from at least one of said further processed portions ($\hat{\hat{s}}_2$ to $\hat{\hat{s}}_4$) of the received signal from the received spread OFDM signal (y).

3. A method as claimed in claim 1 or 2 further comprising iterating processing the signal block, including iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion with values derived from the further processed portions ($\hat{\hat{s}}_1$ to $\hat{\hat{s}}_4$) in place of previously processed portions ($\hat{s}_1$ to $\hat{s}_4$), to recover still more reliable estimates for each of the portions.

4. A method as claimed in claim 3 wherein iterating processing the signal block includes splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^j of portions ($\hat{s}_1$ to $\hat{s}_4$), where j is a positive

integer greater than i so that iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed portion is performed with a greater number of portions than the previous steps.

5. A method as claimed in any preceding claim wherein said equalizing steps comprise multiplying by a first diagonal matrix having elements dependent on channel coefficients; and
multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.

6. A method as claimed in any preceding claim wherein said equalizing steps comprise performing minimum mean square error equalization.

7. A receiver (160-180) for use in a spread OFDM wireless communication system (100), the receiver comprising
means for receiving a spread OFDM wireless communication signal, and decoding means for decoding the received signal by a method as claimed in any preceding claim, said decoding means comprising:
equalizing and decision means for performing said equalizing and decision function on the received spread OFDM signal (*y*),

means for splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^i of portions ($\hat{s}_1$, $\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$), such that $\hat{s} = \begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \\ \vdots \end{bmatrix}$, where i is positive integer;

characterised by:

subtracting means for subtracting, for each of said portions ($\hat{s}_1$) of the equalized and decided signal block in turn, said values M ($M\begin{bmatrix} 0 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \\ \vdots \end{bmatrix}$) derived from the decided other portions ($\hat{s}_2$ to $\hat{s}_4$ ...) of the equalized and decided signal block from the received signal block (y) to produce a respective difference signal, where $M = H \cdot W$, H is an $N \times N$ diagonal matrix related to the complex frequency channel attenuations and W is an $N \times N$ unitary spreading matrix;

said equalizing and decision means being arranged to perform said equalising and decision function on the respective difference signal to produce said further processed equalized and decided portion ($\hat{\hat{s}}_1$) of the received signal in which interference due to the other portions ($\hat{s}_2$ to $\hat{s}_4$) of the equalized and decided signal block is substantially reduced;

and said decoding means being arranged to repeat, for each of the other portions ($\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$) of the signal block, said steps of producing the respective difference

signal and performing the equalising and decision function to produce the further processed equalized and decided portion.

8. A receiver as claimed in claim 7 wherein said subtracting means is arranged so that repeating subtracting the values derived from the other portions of the equalised and decided signal block from the received signal to produce a respective further difference signal comprises subtracting values derived from at least one of said further processed portions ($\hat{\hat{s}}_2$ to $\hat{\hat{s}}_4$) of the received signal from the received spread OFDM signal (y).

9. A receiver as claimed in claim 7 or 8 wherein said decoding means is arranged to iterate processing the signal block, including iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion with values derived from the further processed portions ($\hat{\hat{s}}_1$ to $\hat{\hat{s}}_4$) in place of previously processed portions ($\hat{\hat{s}}_1$ to $\hat{\hat{s}}_4$), to recover still more reliable estimates for each of the portions.

10. A receiver as claimed in claim 9 wherein said decoding means is arranged so that iterating processing the signal block includes splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^j of portions ($\hat{s}_1$ to $\hat{s}_4$), where j is positive integer greater than i so that iterating the steps of producing the

respective difference signal and performing the equalising and decision function to produce the further processed portion is performed with a greater number of portions than the previous steps.

11. A receiver as claimed in any of claims 7 to 10 wherein said equalizing and decision means comprises matrix multiplication means for multiplying by a first diagonal matrix having elements dependent on channel coefficients and by a second matrix which is a subset of a Walsh Hadamard matrix.

12. A receiver as claimed in any of claims 7 to 11 wherein said equalizing and decision means comprises means for performing minimum mean square error equalization.

for multiple antennas systems in the publication by G.J. Foschini and M.J. Gans, "On Limits of Wireless Communications in a fading Environment when Using Multiple Antennas", *Wireless Personnal Communications* 6:311-335, 1998. However, it has been demonstrated (in the publication by P. Loubaton, M. Debbah and M. de Courville, "Spread OFDM Performance with MMSE Equalization", in *International Conference on Acoustics, Speech, and Signal Processing*, Salt Lake City, USA, May 2001) that V-BLAST algorithms are not suited for conventional SOFDM systems due to the averaging of the SNRs (signal/noise ratios) at the receiver across the carriers during the despreading step. Moreover, such approaches lead to a tremendous decoding complexity due to the computation of several pseudo inverse matrices.

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In one embodiment of the present invention, the decoding algorithm comprises splitting a received block into two equal parts, one of the parts being decoded first and then subtracted from the received vector to suppress part of the interference and the other of the parts being decoded next. This iterative procedure can be further extended by successive block splitting and results in a multi-resolution decoding algorithm. An attractive property of this algorithm is that although it still relies on the computation of pseudo-inverses, the expressions of these pseudo-inverses are easy to derive and may consist simply in the product of a diagonal matrix by a Walsh Hadamard transform. Thus, using Walsh Hadamard spreading sequences, the inherent complexity penalty of a V-BLAST decoding schemes is simply removed. This allows a significant gain in performance (e.g., around 3-4dB compared to MMSE SOFDM) with only a modest increase in complexity, which motivates:

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The following technical merits of the multi-resolution decoding algorithm of this embodiment of the present invention can be highlighted:

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- Flexibility and scalability of the method (it is possible to adjust the number of iterations to be

performed based on a performance/complexity tradeoff).

- Can be combined into all OFDM standards as a proprietary transmission mode (since it can be

Claims

1. A method of decoding a received spread OFDM wireless communication signal comprising:
performing an equalizing and decision function on the received spread OFDM signal (y),
splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^i of portions ($\hat{s}_1$, $\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$),

such that $\hat{s}=\begin{bmatrix}\hat{s}_1\\ \hat{s}_2\\ \hat{s}_3\\ \hat{s}_4\\ \vdots\end{bmatrix}$, where i is positive integer;

characterised by:
for each of said portions ($\hat{s}_1$) of the equalized and decided signal block in turn subtracting values M ($M\begin{bmatrix}0\\ \hat{s}_2\\ \hat{s}_3\\ \hat{s}_4\\ \vdots\end{bmatrix}$)derived from the other portions ($\hat{s}_2$ to $\hat{s}_4$ ...) of the equalized and decided signal block from the received signal block (y) to produce a respective difference signal, where $M=H\cdot W$, H is an NxN diagonal matrix related to the complex frequency channel attenuations and W is an NxN unitary spreading matrix; and
performing an equalising and decision function on the respective difference signal to produce a further processed equalized and decided portion ($\hat{\hat{s}}_1$) of the received signal in which interference due to the other

portions ($\hat{s}_2$ to $\hat{s}_4$) of the equalized and decided signal block is substantiallyreduced;
the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion being repeated for each of the other portions ($\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$) of the signal block.

2. A method as claimed in claim 1 wherein repeating subtracting the values derived from other portions of the equalized and decided signal block from the received signal to produce a respective further difference signal comprises subtracting values derived from at least one of said further processed portions ($\hat{\hat{s}}_2$ to $\hat{\hat{s}}_4$) of the received signal from the received spread OFDM signal (y).

3. A method as claimed in claim 1 or 2 further comprising iterating processing the signal block, including iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion with values derived from the further processed portions ($\hat{\hat{s}}_1$ to $\hat{\hat{s}}_4$) in place of previously processed portions ($\hat{s}_1$ to $\hat{s}_4$), to recover still more reliable estimates for each of the portions.

4. A method as claimed in claim 3 wherein iterating processing the signal block includes splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^j of portions ($\hat{s}_1$ to $\hat{s}_4$), where j is a positive

integer greater than i so that iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed portion is performed with a greater number of portions than the previous steps.

5. A method as claimed in any preceding claim wherein said equalizing steps comprise multiplying by a first diagonal matrix having elements dependent on channel coefficients; and
multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.

6. A method as claimed in any preceding claim wherein said equalizing steps comprise performing minimum mean square error equalization.

7. A receiver (160-180) for use in a spread OFDM wireless communication system (100), the receiver comprising
means for receiving a spread OFDM wireless communication signal, and decoding means for decoding the received signal by a method as claimed in any preceding claim, said decoding means comprising:
equalizing and decision means for performing said equalizing and decision function on the received spread OFDM signal (y),

means for splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^i of portions ($\hat{s}_1$, $\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$), such that $\hat{s} = \begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \\ \vdots \end{bmatrix}$, where i is positive integer;

characterised by:

subtracting means for subtracting, for each of said portions ($\hat{s}_1$) of the equalized and decided signal block in turn, said values M ($M\begin{bmatrix} 0 \\ \hat{s}_2 \\ \hat{s}_3 \\ \hat{s}_4 \\ \vdots \end{bmatrix}$) derived from the decided other portions ($\hat{s}_2$ to $\hat{s}_4$ ...) of the equalized and decided signal block from the received signal block (y) to produce a respective difference signal, where $M = H \cdot W$, H is an NxN diagonal matrix related to the complex frequency channel attenuations and W is an NxN unitary spreading matrix;

said equalizing and decision means being arranged to perform said equalising and decision function on the respective difference signal to produce said further processed equalized and decided portion ($\hat{\hat{s}}_1$) of the received signal in which interference due to the other portions ($\hat{s}_2$ to $\hat{s}_4$) of the equalized and decided signal block is substantially reduced;

and said decoding means being arranged to repeat, for each of the other portions ($\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$) of the signal block, said steps of producing the respective difference signal and performing the equalising and decision

function to produce the further processed equalized and decided portion.

8. A receiver as claimed in claim 7 wherein said subtracting means is arranged so that repeating subtracting the values derived from the other portions of the equalised and decided signal block from the received signal to produce a respective further difference signal comprises subtracting values derived from at least one of said further processed portions ($\hat{\hat{s}}_2$ to $\hat{\hat{s}}_4$) of the received signal from the received spread OFDM signal (y).

9. A receiver as claimed in claim 7 or 8 wherein said decoding means is arranged to iterate processing the signal block, including iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion with values derived from the further processed portions ($\hat{\hat{s}}_1$ to $\hat{\hat{s}}_4$) in place of previously processed portions ($\hat{\hat{s}}_1$ to $\hat{\hat{s}}_4$), to recover still more reliable estimates for each of the portions.

10. A receiver as claimed in claim 9 wherein said decoding means is arranged so that iterating processing the signal block includes splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^j of portions ($\hat{s}_1$ to $\hat{s}_4$), where j is positive integer greater than i so that iterating the steps of producing the respective difference signal and performing the

equalising and decision function to produce the further processed portion is performed with a greater number of portions than the previous steps.

11. A receiver as claimed in any of claims 7 to 10 wherein said equalizing and decision means comprises matrix multiplication means for multiplying by a first diagonal matrix having elements dependent on channel coefficients and by a second matrix which is a subset of a Walsh Hadamard matrix.

12. A receiver as claimed in any of claims 7 to 11 wherein said equalizing and decision means comprises means for performing minimum mean square error equalization.